A WAVELET ANALYSIS FOR CRACK LOCATION DETECTION ON CANTILEVER BEAM

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ABSTRACT

Over the last few decades, the damage identification methods of civil and mechanical structures have been drawing much interest from various fields. Wavelet analysis, a relatively new mathematical and signal processing tool, is one of such methods that have been studied recently. It is a time–frequency analysis that provides more detailed information about non-stationary signals which traditional Fourier analysis miss. This rather new method has been applied to various fields including civil, mechanical and aerospace engineering, especially for damage detection. The purpose of this paper is to provide the review of the research that has been conducted on damage detection by wavelet analysis. First, the theory of wavelet analysis is presented including continuous wavelet transform followed by its application. This paper proposes damage detection in beam-like structures with small cracks, whose crack ratio [r = Hc/H] in between 10% to 20%, without baseline modal parameters. The approach is based on the difference of the continuous wavelet transforms (CWTs) of two sets of mode shape data which correspond to the uncrack cantilever beam with the crack cantilever beam. The mode shape data of a cracked beam are apparently smooth curves, but actually exhibit local peaks or discontinuities in the region of damage because they include additional response due to the cracks. The modal responses of the crack cantilever beams used are computed using the modal testing method. The results demonstrate whether the crack can be detect on the cantilever beam using the CWT, and they provide a better crack indicator than the result of the CWT of the original mode shape data. The effects of crack location and sampling interval are examined. The experimental and the analysis results show that the proposed method has great potential in crack detection of beam-like structures as it does not require the modal parameter of an uncrack beam as a baseline for crack detection. It can be recommended for real applications.

ABSTRAK

Sejak beberapa dekad yang lalu, kaedah mengenal pasti kerosakan struktur awam dan mekanikal telah menarik minat dari pelbagai bidang. Analisis mengunakan wavelet yang juga merupakan satu kaedah baru dalam memproses isyarat. Analisis ini dapat menyediakan maklumat yang lebih terperinci jika di bandingkan dengan analisis Fourier yang sudah ketinggalan. Tujuan utama laporan ini disediakan adalah untuk mengesan kerosakan pada struktur bahan mengunakan wavelet analisis. Pertama sekali kita perlu memahami teori wavelet analisis sebelum menjalankan kajian terhadap struktur bahan tersebut bagi mengesan kerosakan. Laporan ini mencadangkan dalam mengesan kerosakan struktur dengan mengkaji kerosakan kecil seperti retakan pada struktur bahan tersebut. Nisbah yang dikaji adalah 10% dan 20% retakan yang di bina pada struktur bahan tersebut tanpa ade modal parameter. Pendekatan ini adalah berdasarkan perbezaan dari penjelmaan isyarat perkali yang dikeluarkan oleh struktur yang tiada retakan dan struktur bahan yang mempunyai retakan. Laporan ini menunjukkan perubahan pada isyarat mod yang dipilih antara struktur yang tiada retakkan dan struktur yang ade retakkan. Pada lokasi yang mempunyai retakan yang sebenar dimana pada lokasi 180mm telah mempamirakan puncak yang tertinggi pada perkali wavelet oleh kerana tindak balas tambahan kerana retakkan.Perkali wavelet berkait rapat dengan perubahan amplitude di mana kesan retakan telah menyebabkan perubahan pada tindak balas dinamik pada struktur tersebut di mana kekukuhan bahan tersebut berubah akibat retakan itu. Eksperimen dan keputusan analisis menunjukkan bahawa kaedah yang dicadangkan mempunyai potensi yang besar dalam pengesanan kerosakkan pada. Ia boleh disyorkan untuk aplikasi sebenar.

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LIST OF SYMBOLS

$f\hat{}(\omega)$	Fourier Transform
$\omega(t)$	Window Function
$\psi^{a,b}(t)$	Wavelet Transform
$\psi^{a,b}$	Wavelet
ψ	Mother Wavelet
R_C	Ratio of crack
N	Total number of sampling point
*	Complex Conjugate
H	Height of beam

LIST OF ABBREVIATIONS

CWT	Coefficient Wavelet Transform
FRF	Frequency Response Function
FFT	Fast Fourier Transform
WC	Wavelet Coefficient
NF	Natural Frequency
STFT	Short Time Fourier Transform
TD	Time Domain
FD	Frequency Domain
TFD	Time-Frequency Domain
MS	Mode Shape

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter will briefly explain about the introduction of this project task. The introduction is general information regarding to the topic that will be discuss in this project. This topic will consist of background of proposed study, problem statement, objectives and scope of project. That information is important before further discuss to the analysis and study case later.

1.2 BACKGROUND OF PROPOSED STUDY

The interest in the ability to monitor a structure and to detect damage at the earliest possible stage is pervasive throughout the civil, mechanical and aerospace engineering communities. During the past two decades, a variety of analytical, numerical and experimental investigations have been carried out on cracked structures with a view to developing robust crack location detection methods. Any crack in a structure reduces the stiffness and increases the damping in the structure. Reduction in stiffness is associated with decreases in the natural frequencies and modification of the mode shape of the structure. Several researchers have used mode shape measurements to detect damage. Pandey et al. (1991) showed that absolute changes in the curvature mode shapes are localized in the region of damage and hence can be used to detect damage in a structure. The change in the curvature mode shapes increases with increasing size of damage. This information can be used to obtain the amount of damage in the structure. Ratcliffe (1996) found that the mode shapes associated with higher natural frequencies can be used to verify the location of damage, but they are not as sensitive as the lower modes. Modal curvatures seem to be locally much more sensitive to damage than modal displacements. In fact, Shuncong Zhong. (2005) have shown that higher derivatives give a more sensitive detection. Abdel Wahab and De Roeck (1999) investigated the application of the change in modal curvatures to detect damage in a pre-stressed concrete bridge. They introduced a damage indicator called 'curvature damage factor'.

A crack in a structure introduces a local flexibility that can change the dynamic behaviour of the structure. Some damage index methods require the baseline data set of the intact structure for comparison to inspect the change in modal parameters due to damage. Typically, the baseline is obtained from measurements of the undamaged structure. As an example, Pandey et al. (1991) compared the curvatures of the modes shapes between the undamaged and damaged structures. Sampaio et al. (1999) directly subtracted the values of the mode shape curvature of the damaged structure from that of the undamaged structure.

In recent years, the use of wavelet analysis in damage detection has become an area of research activity in structural and machine health monitoring. The main advantage gained by using wavelets is the ability to perform local analysis of a signal which is capable of revealing some hidden aspects of the data that other signal analysis techniques fail to detect. This property is particularly important for damage detection applications. A review is provided by Peng and Chu (1996) of available wavelet transformation methods and their application to machine condition monitoring. Deng and Wang (1998) applied directly discrete wavelets transform to structural response signals to locate a crack along the length of a beam. Tian et al. (1999) provided a method of crack detection in beams by wavelet analysis of transient flexural wave. Wang and Deng (1998) discussed a structural damage detection technique based on wavelet analysis of spatially distributed response measurements. The premise of the technique is that damage in a structure will cause structural response perturbations at damage sites. Such local perturbations, although they may not be apparent from the measured total response data, are often discernible from component wavelets. Liew and Wang (2002) found that the presence of cracks can be detected by the change of some wavelet coefficients along the length of a structural component.

1.3 INTRODUCTION OF THE PROJECT

Cracks or defect are defining as some material that break or cause to break without a complete separation of the parts. It is the nature of many construction materials to crack as they age and as they expand and contract, particularly with exposure to moisture as they get wet and dry out. The more common of these include concrete, asphalt, stucco, stone, brick, mortar, concrete block, plaster, and drywall (also called sheetrock or Gypsum). Besides that, composite structure material is also to crack as they ages and they expand. Example for steels structure material is Mild Steel. It have received a great deal of attention among many engineering societies worldwide. Many engineers consider Mild Steel as one of the most innovative materials that may overcome the inherited deficiency of reinforcing concrete structures by steel rebars in harsh environments due to corrosion. It is virtually impossible to determine whether cracks are caused by structural failure or by some other cause, or, if caused by structural failure, whether the cause is active and on-going. However, continued cracking could result in failure in those structures and, depending on the proximity damage to the structure.

Almost by definition, structure will crack simply because the material cracks as it dries, cures, and ages. Common cracks can appear at any time in the life of a structure. However, all cracks need to be monitored regularly to determine if they are expanding or lengthening, at which point other problems might be present. Crack present a serious threat to the performance of structures since most of the structural failures are due to material fatigue. For this reason, methods allowing early detection and localization of cracks have been the subject of intensive investigation the last two decades. As a result, a variety of analytical, numerical and experimental investigations now exist such as a wavelet analysis for crack detection.

1.4 PROBLEM STATEMENT

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1.5 OBJECTIVE

The main objective on this research is to improve a better understanding on crack identification using wavelet analysis. The work has been carried out to meet the following specific objective:

i. To obtain the signal response (frequency response function) on each specimens.
ii. To determine the mode shapes that give significant changes to the crack.
iii. To extract the selected mode using continuous wavelet transform.
iv. To determine the location of the crack using wavelet transform.

1.6 SCOPE OF PROJECT

This study was focus on detection of the crack location on cantilever beam. The step consists of:

i. The type of material to be used is mild steel.
ii. Experimental Modal Analysis will be carried out which is using Modal testing (impact hammering).
iii. ME Scope analysis will be applied to get mode shape that give obvious significant change to the crack.

iv. Wavelet Analysis will be applied on the selected mode shape to get the location of the damages by using Continuous Wavelet Transform.

v. Study was only focus on the location detection of crack for cantilever be

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will briefly explain about the literature review of crack identification in structure, modal testing, signal analysis and introduction to wavelet. The sources are taking from the journals, and articles and books. Literature review is helping in order to provide important information regarding previous research which related to this project. Those information are important to know before can proceed further to analysis and study later.

2.2 INTRODUCTION IN CRACK DETECTION

Cracks found in structural elements have various causes. They may be fatigue cracks that take place under service conditions as a result of the limited fatigue strength. They may be also due to mechanical defects, as in the case of turbine blades of jet turbine engines. In these engines the cracks are caused by sand and small stones sucked from the surface of runway. Another group involves cracks which are inside the material. They are created as a result of manufacturing processes. The presence of vibrations on structures and machine components leads to cyclic stresses resulting in material fatigue and failure. Most of the failures of present equipment are due to material fatigue. It is very essential to detect the crack in structures& machine members from very early stage. A crack in a structure induces local flexibility and it results in reduction in natural frequencies and change in mode shapes. Dimarogonus(1976) carried out lot of work on this.

A review of the state of the art of vibration based methods for testing cracked structures has been published by Dimarogonas (1996). A crack in a structure induces a local flexibility which affects the dynamic behaviour of the whole structure to a considerable degree. It results in reduction of natural frequencies and changes in mode shapes of vibration. An analysis of these changes makes it possible to identify cracks. Dimarogonas (1976) and Paipetis and Dimarogonas (1986) the crack was modelled as a local flexibility and the equivalent stiffness was computed using fracture mechanics methods. In that vein, Chondros and Dimarogonas (1980) developed methods to identify cracks in various structures relating the crack depth to the change in natural frequencies for known crack position. Adams and Cawley (1979) developed an experimental technique to estimate the location and depth of a crack from changes in natural frequencies Gudmunson (1982) used a perturbation method to predict changes in natural frequencies of structures resulting from cracks, notches and other geometrical changes. Further work on crack identification via natural frequency changes was done by Anifantis et al. (1985). Using a similar approach Masoud et al. (1998) investigated the vibrational characteristics of a prestressed fixed–fixed beam with a symmetric crack and the coupling effect between crack depth and axial load. Narkis (1993) developed a closed form solution for the problem of a cracked beam, which he applied to study the inverse problem of localization of cracks on the basis of natural frequency measurements. The main reason for the popularity of natural frequencies as damage indicators is that natural frequencies are rather easy to determine with a high degree of accuracy. A sensor placed on a structure and connected to a frequency analyzer gives estimates of several natural frequencies.

The idea of using mode shapes as crack identification tool is the fact that the presence of a crack causes changes in the modal characteristics. Rizos et al. (1990) suggested a method for using measured amplitudes of two points of a cantilever beam vibrating at one of its natural modes to identify crack location and depth. Recently, an interesting comparison between a frequency—based and mode shape—based method for damage identification in beam like structures has been published by Kim et al. (2003). The advantage of using mode shapes is that changes in mode shapes are much more sensitive compared to changes in natural frequencies. Using mode shapes, however, has some drawbacks. The presence of damage may not significantly influence mode shapes of the lower modes usually measured. Furthermore, environmental noise and choice of sensors used can considerably affect the accuracy of the damage detection procedure. To overcome these difficulties, modal testing using scanning laser vibrometers have been developed (Stanbridge and Ewing, 1999). The laser vibrometer, used as a vibration transducer, has the advantage of being non-contacting and measures at a controlled position with high accuracy. In the last few years, wavelet analysis has become a promising damage detection tool due to the fact that it is very accurate to detect localized abnormalities in a mode shape caused by the presence of a crack. It has useful localization characteristics and does not require the numerical differentiation of the measured data (Newland, 1994a,b). Wavelet transform can be implemented as fast as the Fourier transform and its main advantage is the fact that the local features in a signal can be identified with a desired resolution. Deng and Wang (1998) applied the discrete wavelet transform to locate a crack along the length of a beam. Wang and Deng (1999) extended the analysis to a plate with a through-thickness crack. In the last study, the Haar wavelet were used with success. However, a method for estimating the crack extend has not been proposed. Haar wavelets were also used in the study of Quek et al. (2001). The authors were able to accurately detect relatively small cracks under both simply-supported and fixed-ended conditions. Here again, the estimation of the size of the crack is not discussed. Hong et al. (2002) used the Lipschitz exponent for the detection of singularities in beam modal data. The Mexican hat wavelet was used throughout the study and the crack size has been related to different values of the exponent. In the present work, a method for crack identification in beam structures based on wavelet analysis is presented. The fundamental vibration mode of a cracked beam is wavelet transformed and both the location and size of the crack are estimated. For this purpose, a ‘‘symmetrical 4’’ wavelet having two vanishing moments is utilized. The position of the crack is located by the variation of the spatial signal at the site of the crack due to the high resolution property of the wavelet transform. To estimate the size of the crack, an intensity factor is defined which relates the size of the crack to the coefficients of the wavelet.

2.3 EXPERIMENTAL MODAL ANALYSIS

Modal analysis is a method to describe a structure in terms of its natural characteristics which are the frequency, damping and mode shapes. Modal analysis involves process of determining the modal parameters of a structure to construct a modal model of the response. The modal parameters maybe determined by analytical means, such as finite element analysis, and one of the common reasons for experimental modal analysis is the verification or correction of the results of the analytical approach (model updating). Predominately, experimental modal analysis is used to explain a dynamics problem, vibration or acoustic that is not obvious from intuition, analytical models, or previous similar experience. Theoretical [Finite Element Analysis (FEA)] and Experimental Modal Analysis (EMA) have been very separate engineering activities aimed at solving above mentioned common problem. Now the two technologies are converging and powerful new tools for solving noise and vibration problems are emerging as a result.

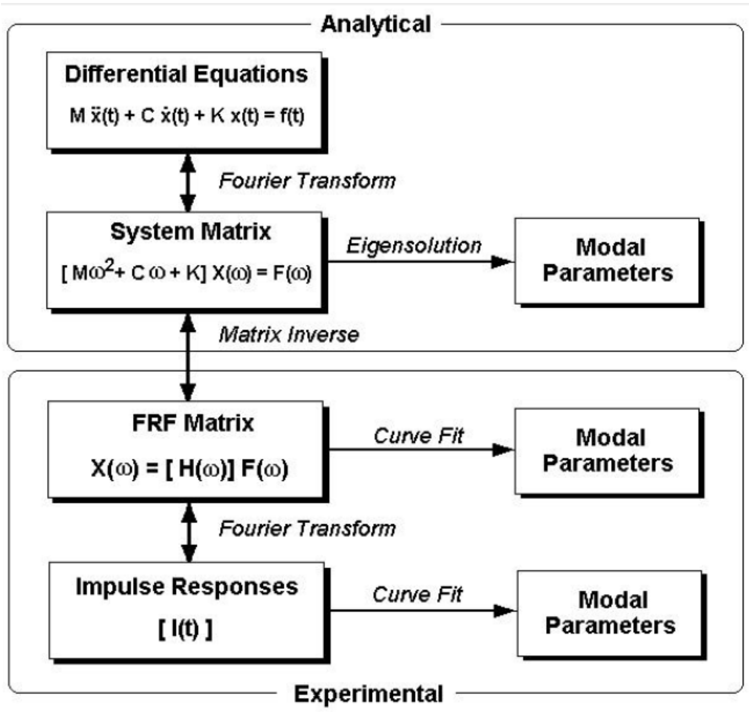

Figure 2.1: Equation of analytical and experimental.

Source: B& K Application Note.

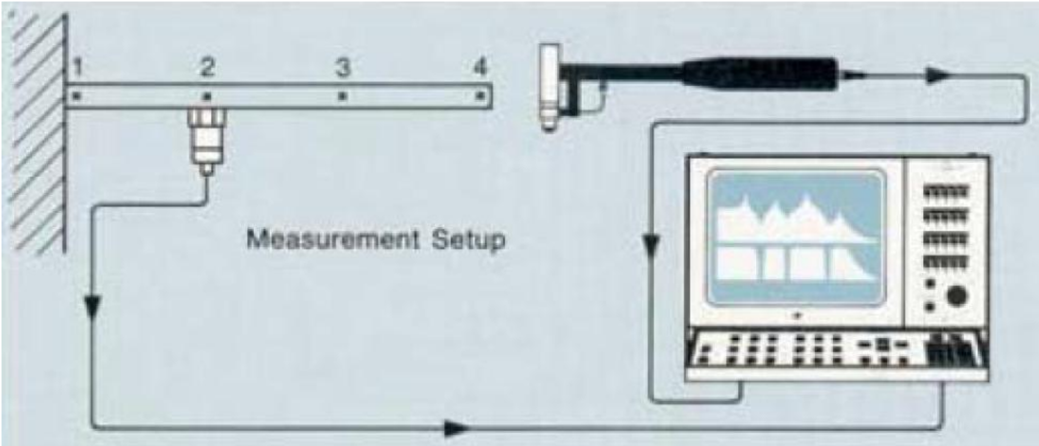

Figure 2.2: Modal Testing Impact hammering.

Source: B& K Application Note.

Modal testing is one of famous method in vibration. Modal testing can be achieved by introducing a forcing function into a certain structure, usually with some type of shaker and familiar ways that are usually be used is like a impact testing or some shaker that used in the lab. In other words, a structure that want to be tested is attached to the table of contain shaker, like a surface containing a few spring that can be shake during handling an experiment. Instantly, for a relatively low frequency forcing, an electronic devices called as a servo hydraulic are used and for higher frequency an electrodynamics shakers are used. In my project, excitation forces is prefer to come from an impact hammer as it is not complicated and easily can be used. For this crack identification which used a modal testing as an experiment, the prefer way to give force to the beam is by the impact hammer. When we use this impact hammer, it gives a perfect impulse which has an infinitely small duration causing constant amplitude in the frequency domain, resulting in all modes of vibration being excited with equal energy.

2.4 SIGNAL ANALYSIS

Signal analysis is an area of systems engineering and applied mathematics that deals with operations on or in other words we call it as signal processing. Signal analysis can be including sound, images and sensor of data like control systems signal, transmissions signals and many others. There are several categories in signal analysis which is signal acquisition, quality improvement and also feature extraction. Based on the research done and journal, suitable categories will be signal acquisition as it involves measuring a physical signal, storing it and possibly later rebuilding the original signal. In this experiment signal analysis can be get by the DasyLab software and also Ansys software.

2.4.1 Time Domain Analysis

Time domain is the analysis of mathematical function, physical signals or time series of economic or environmental data, with respect to time. In the time domain, the signal or function value is known for all real number, for the case of continuous time, or at various separate instants in the case of discrete time. An oscilloscope is a tool used to visualize real world signal in the time domain. A time domain graph shows how a signal changes with time.

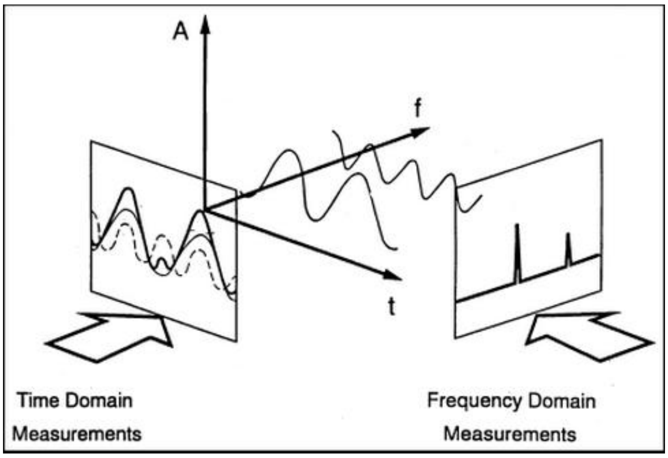

Figure 2.3: Time Domain and Frequency Domain Graph.

Source: B& K Application Note.

Example of time domain analysis in crack detecting to determine if it is feasible to detect and size cracks with the time-domain wave propagation techniques and to recommend the best field-test configuration to be used. A finite element program was used to model a cracked medium. Several parameters were considered the location of source and receivers relative to the crack, the depth of the crack, the width of the crack, and the duration of the source impulse. Major parameters that significantly affect the waveforms were identified by performing a sensitivity analysis on each parameter. The most significant feature that can be used to predict the crack is the existence of standing wave energy detected in the waveforms from receivers located relatively close to the downstream end of the crack. The best test setup is obtained when the source and one receiver are located close to the crack on one side of a crack and a second receiver located on the opposite side of the crack at a distance from the crack. Imran, I., Nazarian, S., and Picornell, M. (1995).

2.4.2 Frequency Domain Analysis

Frequency domain is a method used to analyze data. This refers to analyzing a mathematical function or a signal with respect to the frequency. Frequency domain analysis is widely used in fields such as control systems engineering, electronics and statistics. Frequency domain analysis is mostly used to signals or functions that are periodic over time. This does not mean that frequency domain analysis cannot be used in signals that are not periodic. The most important concept in the frequency domain analysis is the transformation. Transformation is used to convert a time domain function to a frequency domain function and vice versa. The most common transformation used in the frequency domain is the Fourier transformations. Fourier transformation is used to convert a signal of any shape into a sum of infinite number of sinusoidal waves. Since analyzing sinusoidal functions is easier than analyzing general shaped functions, this method is very useful and widely used.

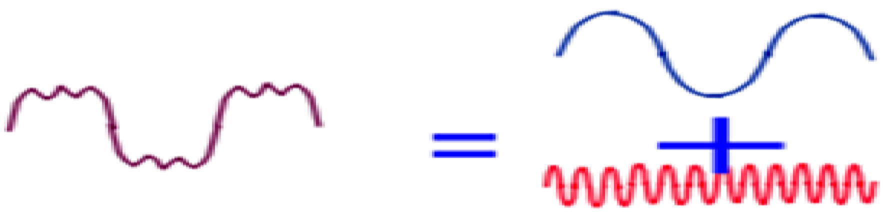

Figure 2.4: Frequency domain.

Source: B& K Application Note.